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Is there a trend in CT scanning scaphoid nonunions for deformity assessment?—A systematic review

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ABSTRACT

Purpose: The effect of scaphoid nonunion deformity on wrist function is uncertain due to the lack of reliable imaging tools. Advanced three-dimensional (3-D) computed tomography (CT)-based imaging techniques may improve deformity assessment by using a mirrored image of the contralateral intact wrist as anatomic reference. The implementation of such techniques depends on the extent to which conventional CT is currently used in standard practice. The purpose of this systematic review of medical literature was to analyze the trend in CT scanning scaphoid nonunions, either unilaterally or bilaterally.

Materials and methods: Using Medline and Embase databases, two independent reviewers searched for original full-length clinical articles describing series with at least five patients focusing on reconstructive surgery of scaphoid nonunions with bone grafting and/or fixation, from the years 2000–2015. We excluded reports focusing on *only* nonunions suspected for avascular necrosis and/or treated with vascularized bone grafting, as their workup often includes magnetic resonance imaging. For data analysis, we evaluated the use of CT scans and distinguished between uni- and bilateral, and pre- and postoperative scans.

Results: Seventy-seven articles were included of which 16 were published between 2000 and 2005, 19 between 2006 and 2010, and 42 between 2011 and 2015. For these consecutive intervals, the rates of articles describing the use of pre- and postoperative CT scans increased from 13%, to 16%, to 31%, and from 25%, to 32%, to 52%, respectively. Hereof, only two (3%) articles described the use of bilateral CT scans.

Conclusion: There is an evident trend in performing unilateral CT scans before and after reconstructive surgery of a scaphoid nonunion. To improve assessment of scaphoid nonunion deformity using 3-D CT-based imaging techniques, we recommend scanning the contralateral wrist as well.

1. Introduction

A scaphoid nonunion is the result of a failed healing of the bone once fractured. A nonunion through the body of the scaphoid is associated with a flexion deformity in which the distal fragment rotates to the palmar side—a so-called humpback deformity [1]. It is also associated with a dorsal intercalated segment instability (DISI) deformity in which the lunate together with the proximal scaphoid fragment rotates in a pathological extended stance. Scaphoid nonunion patients with no or only limited carpal osteoarthritis are usually treated with reconstructive surgery directed at achieving both union and carpal realignment, to improve clinical outcome [2]. A common technique to realign the midcarpal joint is the use of an interpositional structural bone graft in addition to scaphoid screw fixation. This graft is usually harvested from the iliac crest and inserted between the scaphoid fragments through an open volar approach [1].

It is currently unclear how close the restored scaphoid anatomy must be to the original intact anatomy to yield a good clinical outcome [3]. Some clinical articles suggested an association of scaphoid malalignment, with pain, loss of motion and weakness after fracture healing [4–6]; while others failed to show an association between radiologic measurements of the intrinsic scaphoid morphology and outcome [3,7]. A factor contributing to this uncertainty is the unreliable way of measuring scaphoid deformity on both pre- and postoperative images, for which there is currently no consensus about the optimal measuring method [8–10]. On standard radiographs the projection of overlapping bones may hamper obtaining good visualization of the intrinsic scaphoid morphology [10]. Additional computed tomography (CT) provides more detailed information about the bony architecture [11]. Still, standard CT measures of scaphoid deformity only provide two-dimensional (2-D) information (Fig. 1), while the displacement pattern and fracture line morphology in scaphoid non-

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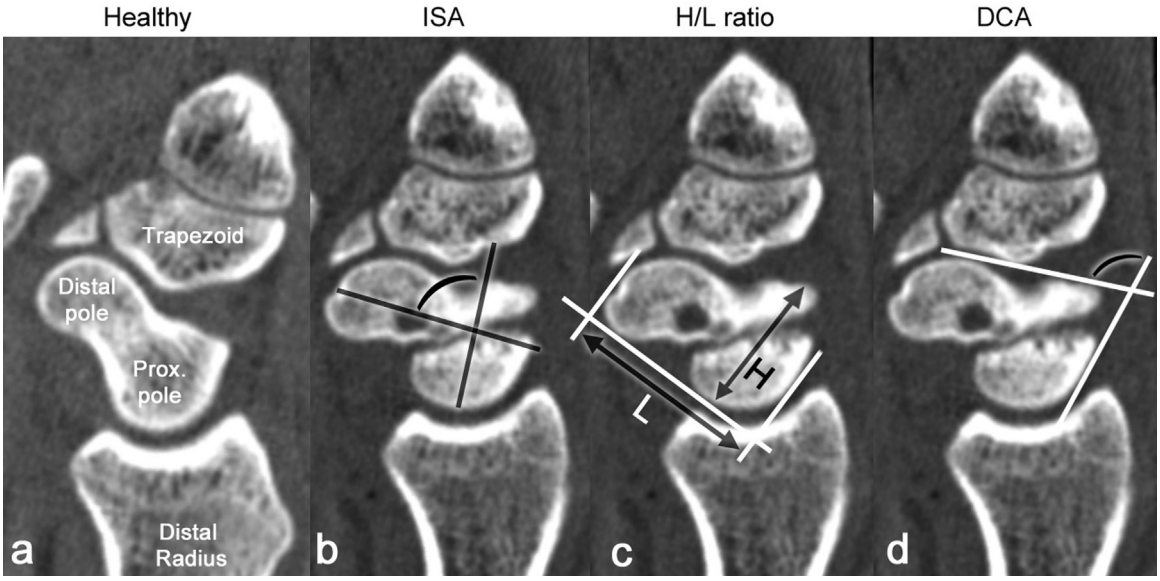

Fig. 1. Sagittal CT slices of both wrists of a patient with a unilateral scaphoid waist nonunion (a) healthy intact scaphoid. (b), (c), and (d) scaphoid nonunion showing a typical humpback deformity as evaluated with standard CT measures [12], including (b) Intrascaphoid angle (ISA); the angle between the two lines perpendicular to the proximal and distal articular surface of the scaphoid nonunion, (c) Height-to-length (H/L) ratio; the ratio between the height of the scaphoid as measured from a palmar baseline to the dorsal humpback, and the length along the palmar baseline limited by the most proximal and distal aspects of the scaphoid, and (d) Dorsal cortical angle (DCA); the angle between two lines along the dorsal cortex of the proximal and distal fragments.

unions are three-dimensional (3-D) problems [12–15]. Moreover, these CT measures have shown to have limited reproducibility [16–18]. Therefore, surgeons stress the need for new imaging methods to more accurately and reproducibly measure scaphoid deformity [3,18].Recent advances in imaging techniques enable synthesizing the information from a standard CT into virtual 3-D models of the scaphoid nonunion fragments. Reconstruction of a 3-D model is often based on a 3-D polygon created from a sequence of segmented 2-D CT images. Currently, many image segmentation and 3-D reconstruction methods exist which can be applied in (semi-)automated fashion [19]. To assess the level of fragment displacement objectively, a mirrored model of the contralateral intact scaphoid may serve as anatomic template, requiring a bilateral CT scan. Using dedicated planning software, the proximal and distal fragments can be virtually matched with the proximal and distal intact poles by image registration [12–15]. Subsequently, fragment displacement can be defined as the difference in position between the distal fragment and the intact distal pole relatively to the proximal fragment. To express displacement in 3-D space, an anatomical coordinate system can be defined based on the principal axes of the virtual model of the contralateral intact scaphoid using its inertial properties (Fig. 2) [20]. The contralateral scaphoid is considered an accurate template because of the reported high level of bilateral shape symmetry in scaphoid pairs [21]. These advanced imaging techniques may improve characterizing scaphoid nonunions as well as investigating the relation between the level of scaphoid deformity and clinical outcome.

The clinical implementation of advanced 3-D CT-based imaging techniques is influenced by the extent to which conventional CT is currently used in standard practice. Numbers about the exact rate of using CT in the management of scaphoid nonunions are lacking. The purpose of this systematic review was to analyze the use of CT as reported in clinical series on reconstructive surgery of scaphoid nonunions, with special interest in the ability of CT to generate 3-D CT-based images. We addressed the following questions:

1. Is there a trend in CT scanning scaphoid nonunions, either unilaterally or bilaterally?
2. Is there a difference between the pre-operative and postoperative use of CT?
3. Which CT measures of scaphoid humpback deformity are most commonly applied?

2. Material and methods

We conducted an online literature search in Medline and Embase from 2000 to 2015. The search and data extraction were performed by two independent reviewers, according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines [22]. Disagreements between reviewers were discussed until consensus was reached.

2.1. Eligibility criteria systematic review

All reports on the reconstructive surgery of scaphoid nonunions not suspected for avascular necrosis (AVN) were eligible for inclusion. We excluded reports focusing *only* on scaphoid nonunions with or suspected for AVN, proximal nonunions and/or scaphoid nonunions treated with vascularized bone grafting, as their workup often includes magnetic resonance imaging (MRI). To increase power, studies comparing both non-vascularized and vascularized bone grafting were included, with special attention to the non-vascularized treatment group. Inclusion criteria were: (1) original full-length clinical articles focusing on reconstructive surgery with non-vascularized bone grafting and/or fixation for scaphoid nonunions; (2) series of at least five adult patients; (3) publication date between 01.01.2000 and 31.12.2015; (4) English language. Exclusion criteria were: (1) non-clinical studies; (2) series focusing *only* on vascularized or osteocartilaginous bone grafting; (3) series including *only* proximal nonunions; (4) diagnostic studies focusing on MRI; (5) non original full-length articles; (6) follow-up studies based on series already described in previous included articles from the same institution.

2.2. Literature search, study selection and data extraction

We used Medical Subject Headings (MeSH) (= scaphoid bone), using free search terms in title and abstract with (=scaphoid*), and using free search terms in all fields with truncation. The full search strategy is addressed in Fig. 3. We retrieved all titles and abstracts for